SEMI-ANNUAL STATUS REPORT

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The present report covers the second half of the twelfth year of operation under the National Aeronautics and Space Administration Grants NGL 05-002-207 and NCL 05-002-007. The grants support work in two separate fields of study; this semi-annual status report is accordingly divided into two parts. A brief summary of the work in these sub-disciplines is given below in order to present a general overview of the work performed.

## SUMMARY

I. Infrared Astrophysics (G. Neugebauer, E. Becklin, and M. Werner)

The observational program in infrared astrophysics covered wavelengths from the near infrared to 1 millimeter. The program of millimeter observations largely consisted of analyzing previous observations since the summer humidity is too high for new observations. Maps of millimeter emission from W3, Sgr B2, W49 and M42 were made with 1' resolution over areas ~ 5' x 5'. All showed sharp peaks on extended backgrounds with the peaks located at positions of compact H II regions or point infrared sources. Five extragalactic sources were detected and one, 3C273, has been monitored on a bimonthly basis to look for variations.

Energy distributions of several of the discrete sources at the Galactic Center have been obtained. The brightest 2-μ source shows CO absorption identifying it as a late type star while nearby sources have a featureless spectrum consistent with H II regions or planetary nebula. Detailed 8 to 13-μ spectra of W3 and NGC 7538 were also obtained which show the existence of two classes of compact infrared sources.

The 5-year visual/infrared program on Markarian galaxies was completed. It showed convincingly the presence of both thermal and non-thermal infrared radiation sources and established correlations between the infrared sources and the emission line regions.

The Nova Cygnus 1975 was caught during its rise as well as subsequent dimming. Infrared data show the development of the Brackett γ hydrogen line as well as the transition from an optically thick to optically thin emission source. Several other continuing programs are also described, including studies of dark clouds and CO maser sources; a new 1 to 5-μ detector system is described in detail.

II. X-Ray and XUV Astrophysics (G. Garmire and I. Tuohy)

Dr. P. Agrawal and Dr. J. Patterson have left the group during August and Dr. I. Tuohy (from Mullard Space Science Laboratory) has joined the group. Dr. Tuohy has been instrumental in developing and refining the planar-position sensitive proportional (PPSP) counter used by the Mullard group. In terms of the CIT PPSP development, the new evaporated Silicon on sapphire wafers forming the resistive element appear quite uniform. A new counter body is under design based on Dr. Tuohy's experience.

The study of the Monoceros-Gemini and Eridanus soft X-ray enhanced regions has been completed. Reports were presented at the AAS meeting in San Diego and a paper is in preparation. The analysis of UHURU X-ray background data is complete and was reported at the San Diego meeting as well.

Optical observations of HZ 29 were made at Mt. Wilson and Palomar observatories at the time of its discovery by SAS-3. No periodicities or anamalous behavior was detected to distinguish it from other white dwarfs. Photometric measurements of Sco X-1, HZ Her, Cyg X-1 and 3U 1700-37 were carried out over a three month span during June, July and August. No unusual behavior was detected that could be confirmed by later observations.

I. Infrared Astrophysics (G. Neugebauer, E. Becklin, and M. Werner)

The program in ground-based observations over wavelengths ranging from 1.2 μ to 1 mm has continued. In addition to providing basic astrophysical data, the program provides the background for participation of members of the Caltech infrared group in a number of other NASA infrared programs. Specifically, knowledge and experience gained in carrying out this program is crucial for our participation in the LST, the SIRTF, and Explorer infrared survey programs. The ground-based program is also, of course, intimately tied to the group's airborne program using the Kuiper Flying Observatory.

As in previous years, this report will be split into sections dealing with the millimeter and shorter wavelength observations. It is important, however, to stress that the programs are coordinated both in their technical development and scientific content.

Photometry at Millimeter and Sub-millimeter Wavelengths

The program of 1-mm photometry during twilight hours at the 200-inch prime focus has developed over the last three years to the point where observations with high sensitivity are being routinely and reliably made. The sensitivity of the composite bolometer system now in use allows us to reach a limiting flux of $\lesssim$ 1 Jy in one hour on a day of good, but not outstanding, atmospheric transmissions. For comparison, this system thus has about a factor of two better sensitivity than the system used for 1-mm photometry at the Kitt Peak 36-ft telescope. Significantly, the 200-inch system also has a better beam profile providing higher spatial

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resolution and higher pointing accuracy than can be attained at this wavelength at Kitt Peak.

Since the summer months are generally humid at Palomar, the main effort in this program over the past few months has been devoted to the preparation for publication of previously obtained data. The principal results emerging from the data analysis are the following:

A) Mapping of thermal emission from molecular clouds - Maps with 1' resolution covering ~ 5' x 5' have been made of the 1-mm emission from four sources, W3, Sgr B2, W49, and M42 (OMC-1). In each case, the distribution of 1-mm surface brightness shows a sharp peak superposed on an extended background having $\lesssim 25\%$ of the peak brightness. The peak 1-mm flux density into the 1' beam is 35 Jy for W3, 90 Jy for W49, 215 Jy for OMC-1, and 310 Jy for Sgr B2. These fluxes are much too high to be due to free-free emission or unresolved molecular lines, and the 1-mm radiation is almost certainly due to thermal emission from dust. Thus it is noteworthy that the peaks are seen at the positions of compact H II regions and/or point-like infrared sources which are thought from other considerations to be the youngest and/or most dust-embedded objects in each of the regions mapped.

The data have been analyzed in terms of a simple model of a central object heating a surrounding dust cloud in which the dust density decreases radially outward as $\rho(r) \propto r^{-n}$. The best fits to the data are found for values of n between 1.5 and 2. This type of density gradient arises very generally in a variety of gravitational collapse calculations, so the steep density gradients inferred from the 1-mm data may have been produced by the collapse process which led to the formation of the central luminosity source.

B) 1-mm photometry of compact extragalactic objects - This program has resulted in the detection of five sources: 3C84, 3C120, 3C273, 3C279, and BL Lac. The derived fluxes lie in the range of 5 to 20 Jy. Additionally, 3σ upper limits of $\lesssim$ 5 Jy have been set for a number of objects, including NGC 1068, NGC 4151, and M82. None of the sources detected shows any significant 1-mm flux over what is expected from an extrapolation of the microwave spectrum. The latter limits are, however, just at the point where they are becoming significant in differentiating thermal from non-thermal origins for the large amounts of infrared radiation present in these objects. Additionally, 3C273 has been monitored on a bimonthly basis from December, 1973, to June, 1975, and has shown no firm evidence for variation greater than ~ 30% of the mean flux, which is ~ 13 Jy.

Both of these observing programs will be continued in the coming months. Studies of the compact sources will focus on reducing the flux limits to the point where they might constrain models for the shorter wavelength infrared radiation.

Observations from 1 to 20 μ

A very varied program at the shorter infrared wavelengths has been continued. The main thrust has been to utilize the high spatial resolution of the 200-inch telescope combined with its large flux gathering capability, but most of the telescopes at Mt. Wilson and Palomar have been used. In particular, many observations have been made with the Mt. Wilson 60-inch telescope which has been equipped with a low background wobbling secondary thus making it an excellent infrared facility.

Galactic Center - An example of the power of the 200-inch is the continued program of observations in the 1 to 20-μ region of the Galactic center. New and detailed studies of the compact 2.2 and 10-μ sources delineated previously by Becklin and Neugebauer (Ap. J. (Letters), 200, L71, 1975) have been made which include measurements of the CO band at 2.3 μ, the "silicate" absorption feature at 10 μ, and overall energy distributions from 1.5 to 20 μ. CO absorption was definitely found in the brightest 2.2-μ source IRS 7, supporting the hypothesis that this object is an M supergiant at the Galactic center. Observations of the energy distribution from 1.2 to 20 μ also are consistent with this hypothesis. Two other 2.2-μ sources also showed CO absorption, indicating that they are probably individual M giant or supergiant stars.

Interestingly, IRS-1, which is associated with the brightest 10-μ sources, did not show CO absorption; thus the near infrared properties are consistent with IRS-1 being similar to a compact H II region or a planetary nebula. IRS-16, which is at the same position as the very compact sub-arc-second radio source of Balick and Brown, also does not show CO absorption; however, in this case the overall energy distribution from 1 to 10 μ is not at all like an H II region indicating that IRS-16 is somewhat unique even in the infrared.

Observations of the "silicate" feature at 10 μ have been made both with broadband filters and with a spectrometer with resolution of $\Delta\lambda/\lambda \sim 1\%$. The results show that except for IRS-3 all of the 10-μ sources show an optical depth in the "silicate" feature expected from interstellar absorption. The nature of the "silicate" depth in IRS-3 is unclear, but

absorption intrinsic to the source is very likely. The spectrometer results also show the presence of an emission line at 12.3 μ due to ionized Neon in several of the sources. This strengthens greatly the hypothesis that most of the compact 10-μ sources are associated with ionized gas. IRS-3 again is unique in that it shows no emission line and the source is probably an infrared star similar to that found on the CIT 2.2-μ sky survey. In conclusion, it can now be stated that most of the compact infrared sources in the central 2 pc of the Galaxy are either late type M stars, compact H II regions or planetary nebula, or infrared stars such as NML Cyg.

The H II region W3 - Further observations of W3 have discovered the presence of an emission line of Ar III at 8.99 μ, as well as measuring more accurately the Ne II and S IV lines found previously. On the basis of the 8 to 13-μ spectrophotometry and broadband measurements at 5 and 20 μ, the compact sources in NGC 7538 and W3 can be divided into two classes. The first class, which includes NGC 7538, IRS-1 and W3-IRS-3, consists of compact sources whose emission from 5 to 20 μ can be described by a single dust temperature. The second class, which included all of the other sources in the two H II regions, consists of both compact and extended objects which exhibit a range of dust temperatures. The mass of the emitting dust can be deduced for those objects with a single temperature; for the others only a lower limit can be obtained. The mass of ionized gas can also be deduced for those objects which have been observed at radio wavelengths. NGC 7538-IRS-1 has a gas to dust ratio of 75; many of the other objects have upper limits which are below 1000.

Other workers have found that the dust inside H II regions is depleted; little evidence for depletion has been found here.

Extragalactic objects - A long range program of the Caltech infrared group has been directed towards the problem of the nature of the infrared radiation found in several extragalactic objects. During the last half year the cooperative 5-year program of determining the visual to infrared energy distributions of Markarian galaxies was completed. The most significant conclusion from the study probably relates to those 8 members of the program galaxies that are Seyfert galaxies. Specifically, it was found that thermal, non-thermal and stellar radiation components are present in these galaxies. Furthermore, the Seyferts are broken into two subgroups. Broadly speaking, one group of Seyfert galaxies is characterized both by the presence of a high density region of gas and by a continuum dominated by non-thermal radiation. The continua of the remaining Seyferts, which do not have a high density region of gas, are dominated by thermal radiation from dust and a stellar continuum. The ten Markarian galaxies studied which are not Seyfert galaxies were shown to be examples of extragalactic H II regions; there is evidence for thermal emission from dust being present at 10 μ in four of these galaxies.

Two new programs of study of extragalactic objects have been initiated. In one, which is in collaboration with W. Sargent, we plan to measure the complete energy distribution from the visible to the infrared of the known Seyfert galaxies. As part of this program, some initial 10-μ observations have shown the presence of a deep silicate absorption dip in the Seyfert galaxy MKN 231 thus confirming that its infrared radiation is thermal.

In another, the energy distributions of the quasistellar sources brighter than 17 magnitudes will be measured over the visual and infrared wavelength ranges.

X-ray sources - Another continuing program relates to the infrared properties of X-ray sources. During the last 6 months two sources were studied in depth. Cyg X-3, which cannot be seen visually, was observed over a 1-week period in conjunction with X-ray observations with the Copernicus satellite plus radio observations at several observatories. The data have not been compared yet but unfortunately Cyg X-3 was in a quiescent stage and thus no information about the flaring mechanism was obtained. The variable HZ Her was also monitored over a large period of time at 1.6 and 2.2 μ. The data will be combined with measurements obtained with the multichannel spectrometer of the 200-inch in order to determine how the continuum energy distribution changes with the amplitude of variation.

Stellar populations in galaxies - The study of stellar populations in galaxies continued in collaboration with Harvard astronomers Dr. J. A. Frogel (now at Cerro Tololo Inter American Observatory), Dr. S. E. Persson (now at Hale Observatories), and M. Aaronson. The observational program consists of measuring broad and narrow band infrared colors of stars and galaxies, in order to determine the relative contributions of giant and dwarf stars to the composite infrared light. The CO index, which measures the depth of the 2.3-μ stellar CO band, is a sensitive indicator of luminosity for late-type stars. The CO index measured for elliptical galaxies indicates that the bulk of the 2-μ light is contributed by giant stars. This fact, when interpreted within the framework of a synthetic

model for the stellar content and evolution of elliptical galaxies, gives information on the systematic change in visual brightness of galaxies as a function of time. The magnitude of this change can have important consequences for cosmology, since it can be significant over the "look-back time" to distant galaxies used to construct the red shift-magnitude diagram.

The continuing observations are aimed at gaining an understanding of the spatial and spectral distributions of the stars which provide the infrared light of elliptical and spiral galaxies. Changes in the colors and CO index with distance from the galaxy nuclei seem to be present at the few sigma level. These variations could be due either to changes in the relative numbers of dwarf and giant stars, or to a systematic change in the shape of the giant branch caused by metallicity effects. The broadband data give a preliminary indication that the latter effect is the more important. In order to investigate fully the importance of these effects plus the possible presence of very red "CO-strong" stars in the light of elliptical galaxies, more observations are planned, and in progress. These include extending the broadband observations to longer wavelengths, obtaining spectra ($\Delta\lambda/\lambda \sim 0.1$) in the 2-$\mu$ region, and measuring to higher sensitivity, the various parameters away from the nuclei of the galaxies. These data can be used to compare infrared parameters to such galaxy properties as metallicity, morphological type, and absolute luminosity, and can be combined with optical data to strongly constrain synthesis models of the stellar content.

Nova Cygnus 1975 - On 29 August, 1975, Nova Cyg 1975 flared to become the brightest visual star in Cygnus. Luckily, members of the group were at Mt. Wilson at the time and so infrared observations have been obtained during the brightening of the nova and the subsequent dimming. The measurements, which cover wavelengths from 1.2 to 20 μ, are being continued whenever telescope time is available. In addition to broadband photometric measurements, the 2-μ spectrum of the nova has been routinely observed with a resolution of 1%.

The measurements reveal two major phases in the development of the nova. Prior to maximum the 1 to 20-μ data are characteristic of a black body, while the 2-μ spectrum shows hydrogen and helium absorption lines (hydrogen $n = 4 \rightarrow n = 7$, i.e., Bracket γ; helium 1s 2s → 1s 2p singlet). The nova is optically thick at this stage; the absorption lines are produced by resonant scattering close to the boundary of the expanding gas.

At about the time of maximum light the nova begins to become optically thin. The 1 to 20-μ data reveal a flat ("free-free") spectrum, while the hydrogen and helium lines previously seen in absorption go over into emission. The transition from optically thick (blackbody) to optically thin ("free-free") takes on the order of two days. Continued observations have shown the nova becoming fainter at all wavelengths, with little change in the appearance of the infrared spectrum

The nova will continue to be monitored for evidence of an "infrared phase" such as was seen in Nova Serpentis (1970), in which the 10-μ brightness increased sharply as dust condensed out of the ejecta produced by the explosion of the nova.

Occultation size observations - Observations of the size of the emitting regions in the long period variable U Ori have been made at 2.2 and 10 μ by means of a lunar occultation. The results show that the 2.2-μ radiation comes from the photosphere of the star which is about 0.03" in diameter, while the 10-μ radiation comes from a region 0.3" in diameter. The 10-μ radiation is interpreted as coming from a dust shell; the size of the dust shell is approximately the same as that for the other OH emitter IRC+10011.

Infrared properties of OH masers - The 60-inch telescope at Mt. Wilson, which has recently become operational as a good infrared telescope, was used in the continued program related to OH maser sources. The work was done in collaboration with N. Evans of O.V.R.O. Discovery of the infrared sources associated with OH1821-12 (Hardebeck, 1972) and OH21.4-0.7 (Evans et al., in preparation) as well as measurements of ON-4 at 10 μ and 20 μ concluded the observations of 1612 MHz, Type II OH maser emitters (Wilson and Barrett, 1971). The major results of the study are:

1. Of the 8 OH maser sources included in the study, every one has an associated infrared source.
2. Of five sources followed for more than one year, four were found to vary both in the infrared (2 to 20 μ) and at 18 cm. In all cases the infrared and radio fluxes varied in the same sense.
3. One of the infrared sources, that associated with OH30.2-0.3, is shown to have 2.4-μ CO band characteristic of stars with spectral type later than K.

4. Based on the observed flux at 3.4 μ and 12.5 μ, infrared pumping of the 1612 MHz radio line is possible at 34 μ but not at 2.8 μ.

Work continued on the properties of 1665 MHz OH masers with the discovery of two more infrared sources associated with the 1665 MHz masers OH35.6 and OH40.6 (Evans et al., in preparation). The infrared sources are very weak and there appears to be no correlation between near infrared flux and 1665 MHz line strength in all of the sources studied. No property characteristic of infrared sources associated with these masers has been found.

Dark clouds - Scanning of dark clouds has continued. To date, three small cloud complexes have been scanned, those near IC 5146, NGC 7023 and Sharpless 239. In addition, scanning of the two closest large complexes, in Taurus and Ophiuchus, has continued. Scanning of these regions is half to two thirds completed.

The results to date demonstrate that the sources detected so far--about $10^3$--are for the most part background objects similar to those detected by earlier, lower sensitivity surveys. Several interesting objects have been found. Some photometry and low-resolution spectrophotometry has been done on these, but the results are not yet fully analyzed and definite conclusions cannot be made.

Instrumentation - Many of the observations discussed above were performed with a new very sensitive and versatile 1.2 to 5-μ detector system which was built and put into operation in the early part of the year. The system has both broadband filters and a continuously variable filter wheel; the latter provides us with a 1% spectrometer either from

1.6 to 3.2 μ or 2.8 to 5.6 μ.At the telescope, the broadband sensitivities of the system are set by the fluctuations in the background radiation except at 1.6 μ or when the small apertures are used.

The system consists of an InSb photovoltaic cell installed in a $LN_2$ jacketed dewar. The dewar is a commercial one which has been extensively modified to include an externally controllable variable aperture of the iris diaphragm type with a range of 0.5 to 8 mm, a simple interchange of diaphragms can extend this range to 12 mm. Provision has been made for the field lens, which is mounted between the cell and aperture, to be focused while the system is assembled and at liquid nitrogen temperatures; this feature is essential since InSb detectors do not function at room temperatures. Mounted on the liquid nitrogen cooled shield is a filter wheel holder that is driven with an intermediate 10 to 1 gear reduction by a rotary feedthrough. The angular accuracy is better than 0.001 of a revolution of the filter wheel holder. Several interchangeable filter wheels can be mounted to position filters between the window and aperture. Various combinations of 1% bandwidth circularly variable filters and fixed 1-inch diameter fixed filters can be inserted in these wheels.

The preamplifier system for the cell is one derived through minor modification from our original high sensitivity InSb detector system. It features low noise and negligible detector bias drift with temperature. The bias may be set at any value over the range ± 100 V so that the cell's current-voltage curve may be measured.

The preamp also incorporates an optically coupled feedback system that nulls the background photo-current generated when using long wavelength filters. The front end components of this preamp are partially on the shield and partially on the inner can of the dewar in order to minimize the noise.

With the present load resistor of $10^{10}$ Ω the zero background noise equivalent power at the window of the dewar is approximately $8 \times 10^{-16}$ $WHz^{-1/2}$ at 2 μ. Under these conditions the limiting noise is almost completely the Johnson noise of the load resistor, since under proper operating conditions the zero bias resistance of the cell is $\geq 3 \times 11^{12}\Omega$. With the addition of the proper load resistor and feedback network it is hoped that this present noise can be reduced by at least a factor of three to that which is now contributed by the input FET.

Visitor Program An increasingly large fraction of the usage of the infrared equipment is devoted to visitor usage. This generally is limited to people in the Caltech/Hale Observatory community. Some programs, e.g. the program of determining stellar populations in galaxies, have evolved to become joint programs. Others, such as programs initiated in the astronomy department by graduate students remain essentially independent. Planetary observations have been made by Westphal and Diner using the 10-μ detector and wobbling f/72 detector developed by this group. Veeder, Matson, and Johnson of JPL have been continuing 0.56, 1.65, and 2.2 μ observations of satellites and bright asteroids. Observations of the Apollo-type asteroid (433) Eros during its recent close approach to earth,

indicate that Eros is relatively bright in the infrared. The results of these observations will appear in the issue of Icarus dedicated to this opposition of Eros. Since Apollo-type asteroids can cross the orbit of Earth, they are considered the probable source of some types of meteorites. The results of observations of Ceres, Pallas, and Vesta have appeared in Ap. J., 197, 527-531. These observations have so far confirmed the presence of carbonaceous chondritic material on the surfaces of Ceres and Pallas. The data for at least 13 more asteroids are being reduced at the present time. Preliminary results indicate that a large range in reflectances, R, are being detected: $R_{2.2\ \mu}$ appears to range from less than 1.0 to greater than 1.7 relative to a normalized reflectance of 1.0 at 0.56 μ. This large range indicates that the classification schemes proposed for asteroids based only on 0.3 to 1.1 μm spectral data are not adequate. Observations of the satellite Iapectus at maximum and minimum light are being continued.

II. X-Ray and XUV Astrophysics (G. Garmire and I. Tuohy)

The analysis of the Gemini-Monoceros and Eridanus soft X-ray enhancements is completed. The results are contained in a Ph.D. thesis by K. Long and will be submitted for publication in a somewhat more compact form in about two months. The main results are that neither region is produced by a few discrete stellar sources. The temperatures are quite low, in the range of 2 to 3 million degrees, and the amount of neutral hydrogen between us and the regions is less than a few times $10^{19}$ atoms/cm$^2$. The emission measure for these regions is very low, and it is possible that most of the soft X-ray emission in the galaxy is the result of many of these regions at various ages combining to form the bulk of the observed flux.

Some effort during this reporting period was spent finishing the analysis of the X-ray background data obtained from the UHURU satellite. The bulk of the analysis had been completed on a small contract with NASA, but because we were furnished rather poor tapes by the UHURU group, the amount of tape editing and reformating required was substantially greater than anticipated. The results were reported by F. Cordova at San Diego in August and a paper is in preparation. The results are rather startling in that they predict that the expected number of high latitude X-ray sources at sensitivities of a few times the UHURU sensitivity is considerably (up to five times) less than predicted by current UHURU source counts. It is unclear why the source counts are overestimates at the low intensity end of the distribution.

Perhaps further analysis of the UHURU background data and source identification criteria will resolve this apparent contradiction.

• The work on the planar position sensitive proportional counter (PPSP) has gone slowly due to the change-over in personnel and unusually heavy demands on the laboratories manpower during the time when flight hardware has been delivered to GSFC on the HEAO-A2 experiment. The silicon coated sapphire disks used for the position sensitive element appear quite good. Now that Ian Tuohy has joined our group from Mullard, we will incorporate the latest improvements in the PPSP counter design.

The scintillation chamber development has gone rather slowly during this period for the same reason. A preliminary chamber was made to work, but it then developed high voltage breakdown problems and the design will have to be modified somewhat. Work on this detector will pick up again this winter.

A ground based program to capitalize on the recent observations of SAS-3, Ariel 5, OSO-8, ANS and the Copernicus satellite has been initiated by Bill Priedhorsky, a graduate student in physics. He has been making photometric observations using the Mt. Wilson 24-inch and the Palomar Mountain 60-inch to observe Sco X-1, Cyg X-1, 3U 1700-37, HZ-Her and HZ 29. So far the observations tend to confirm previous work, although a long search for periodicity in the light from Sco X-1 at a period of around 20 seconds failed to detect any variation as large as 1%. Variations on this time scale and amplitude were reported by Kestenbaum, Angle, Novick and Cocke 1971, Ap. J. Lett. 169, L49. No variation in the optical flux from HZ 29 was detected on time scales

from 0.1 seconds to 10 minutes at a level of several percent. For this reason the optical identification remains tentative until a better position can be obtained.

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